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OBSERVATION AND INTERPRETATION OF PHOTOSPHERIC LINE ASYMMETRY CHANGES NEAR ACTIVE REGIONS

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ABSTRACT: Changes in spectral line asymmetries between regions of quiet sun and regions containing varying amounts of magnetic flux were observed. The observed asymmetry changes are used to deduce parameters that describe the local state of convective overshoot. From these parameters we deduce how the local convective energy flux depends on magnetic fields within the observed regions. Observations were obtained during five separate observing runs between July 1983 and February 1987. We observe FeI 5434 and FeI 6302. Fe 5434 is not split in magnetic regions while 6302 is used to map out the longitudinal component of the field. Additionally we obtain a K-line slit jaw image to locate areas of plage. The observations indicate that magnetic fields decrease the flux carried by convective elements deep in the photosphere, but permit the elements to overshoot higher into the photosphere and temperature minimum regions. The quantitative effect on the convective transport depends strongly on the strength of the magnetic field.

1. INTRODUCTION

The correlation between velocity and temperature fluctuations associated with fine-scale solar granulation produces the well-known convective blue-shift of photospheric lines, when the lines are observed with insufficient spatial resolution to resolve the granulation (Beckers and Nelson, 1978; Dravins et. al., 1981). It is also well established that the characteristic C-shape of bisectors of spatially unresolved photospheric lines results from this granular velocity-temperature correlation (Voigt, 1956; Schroter, 1957; Nordlund, 1979). Reviews of observations and models are available in Magnan and Pecker (1974) for earlier work and Dravins (1982) for more recent contributions.

Changes in the structure of the solar granulation caused by magnetic fields produce wavelength shifts of photospheric lines and changes in their shapes (Livingston 1982, 1984; Kaisig and Schroter, 1983; Miller, Foukal and Keil, 1984; Righini et. al., 1984; Cavallini et. al., 1985, 1987). Because of these shifts and shape changes induced by changes in the granulation, measurements of flows associated with magnetic regions need very careful interpretation.

Livingston (1982) measured the profile of Fe 5250 (Landre g = 1.5) from areas of the sun having high and low magnetic flux and found the bisector to be red-shifted in the magnetic region with-respect-to the non-magnetic region. The position of the line core changed very little between the two regions. Livingston found similar results for Fe I 5576 (g = 0), indicating that the Landre g-factor does not influence the measurement. Miller, Foukal and Keil (1984) measured three other FeI lines, 5434, 4065, and 5233 and obtained very similar results between network and cell profiles, where network profiles represent averages over regions exhibiting high Ca II K-line emission and cell profiles are averages over regions showing low Ca II K-line emission. They found the network profiles were red-shifted with-respect-to the cell bisectors. Fe 5434 and 4065 showed small core blue-shifts in the network, but the shifts (50km/sec) were not much larger than the uncertainty in the measurements. Their observations were made in regions of the quiet Calcium network (away from sources of activity).

Kaisig and Schroter (1983) measured profiles for six FeI lines formed in both plage regions near sunspots and quiet regions of the disk. They find strong blue-shifts in the cores of Fe 5434, 5635, 5395 and 5576 (> 200 m/sec) and somewhat weaker blue-shifts in Fe 5855 and 5560. Their results for 5434 can be compared directly with those of Miller, Foukal and Keil. The observed changes between plage and non-plage regions are remarkably different in the two papers. The difference in the results could be interpreted as differences in magnetic strength near sunspots and in the quiet network. Cavallini et. al. observed Fe I 6301.5, 6302.5 and 6297.8 in three different active regions of varying magnetic strength. They find that, near disk center, the active region bisector is always red-shifted with-respect-to the quiet sun profile and that the amount of red-shift is

directly proportional to the field strength. At about 0.56 solar radii from disk center they observe a slight blue shift of the magnetic profile. They comment that larger shifts correspond to stronger fields and that there is a correlation between field strength and bisector shape.

Both the Cavallini *et. al.* measurements and the Kaisig and Schroter measurements depend on temporal averaging of the data to cancel the effects of the five-minute oscillations. Both papers use ten manifestations of the profile to compute a mean and thereby claim this cancels the shifts due to oscillations. However, the amplitudes of the velocity associated with each cycle of the oscillation is not constant. We could expect the residual error in the mean defined over ten cycles to be about 30%. More recent work by Immerschitt and Schroter (1986) indicates that the earlier work of Kaisig and Schroter contains errors, and that the large observed blue-shift is probably not real.

Because of the discrepancies in the observations mentioned above and the lack of statistical significance, we felt in worthwhile to collect a larger set of data and to investigate differences between various types of plage regions, those near sunspots, near isolated filaments, and in quiet regions. This talk is a preliminary report on some of this data.

2. OBSERVATIONS AND REDUCTION

We obtained observations during five different time periods. These were 2-4 July 1983, 9-14 November 1984, 3-8 November 1985, 2 Dec 1986 and 13-15 February 1987. The first two sets of observations were made using film as the detector and the latter observations use CCD arrays. Here we will only report on the CCD data. A complete analysis of all of the data is in preparation.

We use two CCD arrays; FeI 5434 spectrograms are recorded on one array. The other array is split into three spectral regions, one containing FeI 5576, the other two image the right and left circularly polarized components of FeI 6302 as well as a neighboring terrestrial line that is used as a velocity reference. The spectrograph slit was scanned across the solar disk in 200, 0.5" steps. The spatial resolution along the slit is 0.33"/pixel and the slit width was 0.5". Spectral resolution is 9 mA/pixel in 5534 and 6.5 mA/pixel in 6302.

Before beginning a scan we make a set of dark current and gain tables. Several tests were conducted to verify the linearity of the gain corrections. Exposures of a flat field were made using a series of exposure times, differing slit widths, and neutral density filters. We found small deviations from linearity (2-3%) for light levels near the center of the CCD's range. At low light levels the deviations could be large (80-100%) for some of the pixels. Linear correction factors for the gain tables were derived from the exposures with variable slit width.

The FeI 6302 images are used to make a map the line-of-sight component of the magnetic field. The magnetic field was measured using both the line core position and the center-of-mass of the left and right circularly polarized components. For each region scanned we then have $B_z(x,y)$, where z is the direction along the line-of-sight, x the direction along the slit, and y the direction in which the slit is stepped. Similarly, for each region scanned, the FeI 5434 spectrograms are used to generate a velocity map (line core position), $V_z(x,y)$, and intensity maps in both the line core and continuum, $I_0(x,y)$ and $I_c(x,y)$.

The line profile at each x,y point is averaged into a bin that depends on the strength of the magnetic field at that point. The individual profiles are referenced to the average core position over the scan:

$$V_{ref} = <V_z(x,y)>_{x,y}$$

and divided by a reference continuum intensity obtain by fitting a two-dimensional, second order polynomial to the continuum intensity map before adding them into a bin. Bins are created for both positive and negative polarities. The line center and continuum intensity maps are used to exclude profiles formed in sunspots or dark pores from the bin averages, since these profiles are much weaker and usually shifted with-respect to those formed in the surrounding gas.

3. OBSERVATIONAL RESULTS

The observed profile bisectors vary considerably from region to region, but show several consistent properties as a function of magnetic activity.

On November 6, 1985 we scanned USAF\NOAA region 4700. This region emerged on the 5th and continued to grow. Cosine of the heliocentric position angles was $\mu = 0.83$. The region was scanned several times with the scans spaced at 12.5 minute intervals to aid in removing the effects of the five minute oscillations. A small active region at $\mu = 0.82$ was scanned on December 2, 1986. On February 13, 1987 we observed a small plage area at $\mu = 1.0$.

Using the magnetic maps for the regions we have averaged the profiles into bins that depend on the field strength of the emitting region. In Figure 1 bisectors obtained by combining the data from active region 4700 on November 6, 1985, the plage region from December 2, 1986, and the plage region from February 13, 1987 are plotted. The profiles have been averaged into 200G bins. Profiles show a clear separation between negative and positive polarities, with the positive polarities primarily red-shifted and the negative polarities blue-shifted.

In Figure 2 we replot the data, but we do not distinguish between positive and negative polarity. This give a figure that can be easily
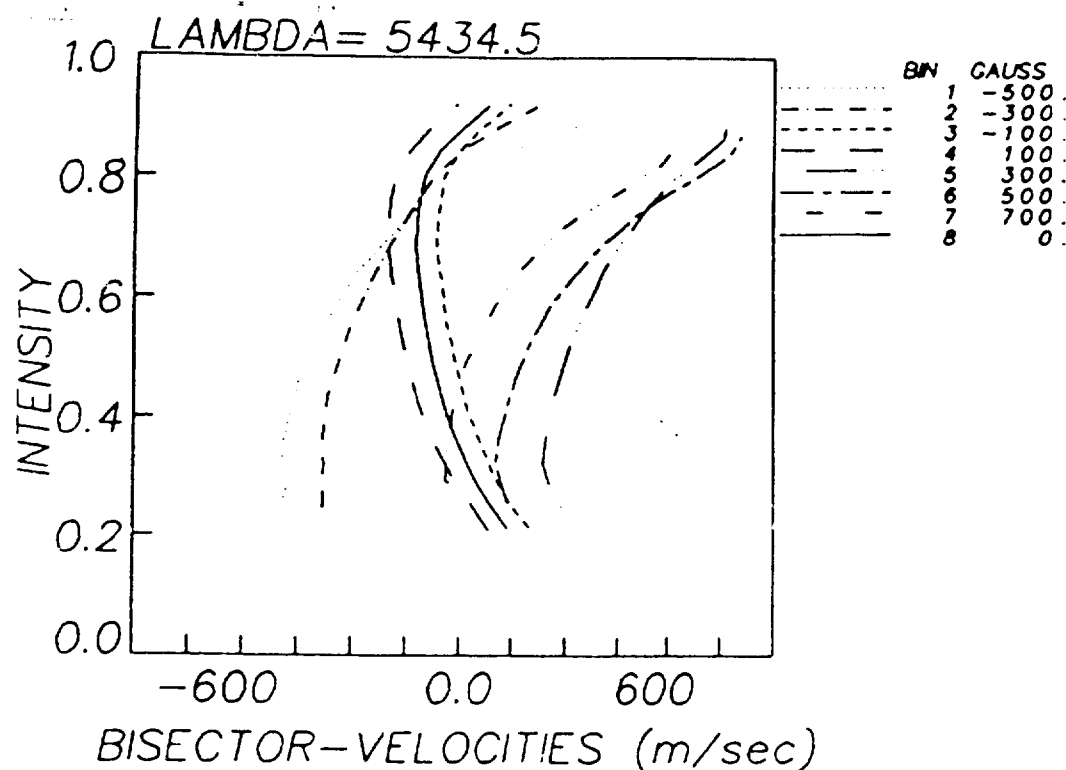
Figure 1. Bisectors of FeI 5434, generated by averaging all of the data from the scans made on November 6, 1985, December 2, 1986 and February 13, 1987, are shown as a function of magnetic field strength. Profiles were averaged into bins that depended on the strength of the local magnetic field. The bins each covered a range of 200 Gauss centered at -500, -300, -100, 100, 300, 500, and 700 Gauss respectively.
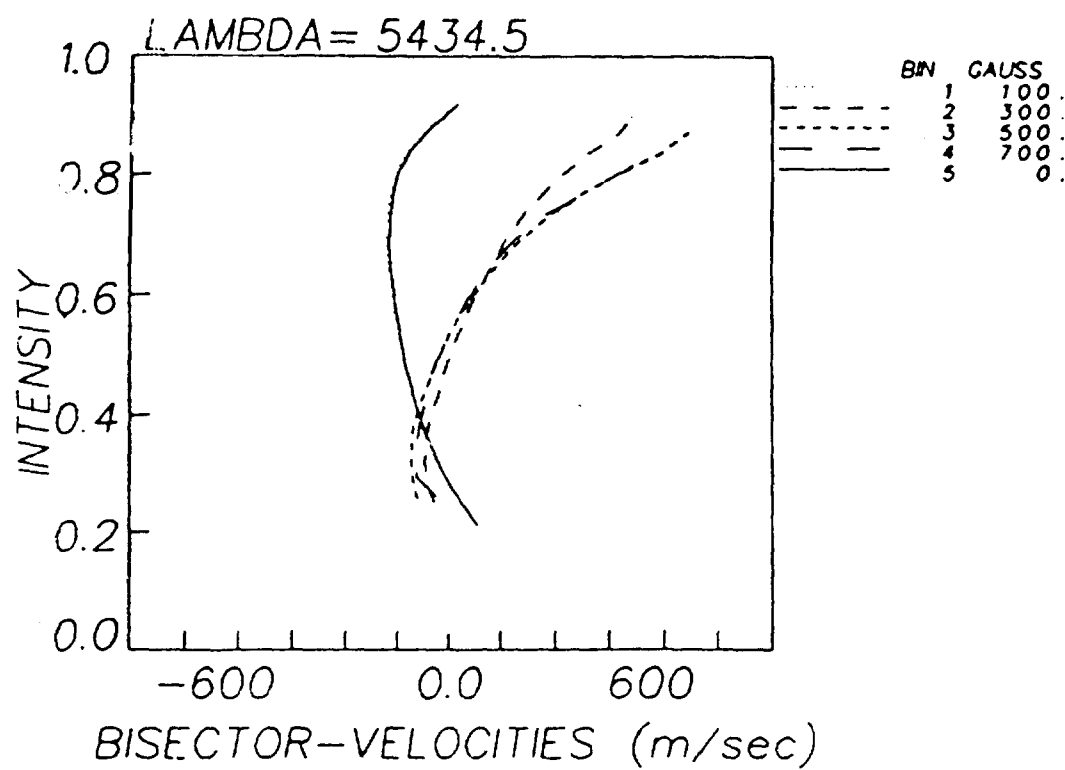
Figure 2.   Bisectors as in Figure 1, however, the sign of the local field was ignored in generating the average for each bin.

compared with earlier work that only separated profiles into plage and non-plage categories. The profiles show a slight core blue-shift and supression of the wings. The bisector of lines from regions exhibiting stronger fields show a greater supression of the red wing.

4. DISCUSSION

Our results can be compared with those of Cavallini et.al. (1985). They observe three FeI lines, all of which have Landre g-factors greater than 1, while we observe FeI 5434 with a g-factor of zero. Their results for active regions near disk center (their Figure 1) can be compared to our Figure 2. Both sets of observations show a strong red-shift in the wings of the line. However, we do not observe the consistent red-shift of the core that they report. Our observations show a slight blue-shift of the core. All of our data was obtained either very near disk center or slightly towards the west limb of the sun.

The data presented here indicate that the line asymmetries vary as a function of field strength and perhaps even polarity of the field. Since the bulk of the data in Figure 1 comes from positions on the disk westward of the central meridian, the separation between polarities could be caused by flows along the fields that project differently for each polarity. For example, if one polarity is consistenly closer to the limb and a downflow along the field line exists, it would have a component towards us for one polarity and away from us for the other.

It is clear from the observations that further work is needed to systematically determine the effects of magnetic fields on convection. The observations are consistent with the picture that magnetic fields suppress the amplitude of convective velocities and permit convective elements to penetrate higher into the atmosphere. Currently, we are developing dynamical models to explain the individual bisector shapes and will present these results along with a more systematic analysis of the bisectors from a wide variety of regions, both east and west of the central meridian.

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Discussion

SCHRÖTER — Let me add a remark: Presently,Immerschitt and myself have a paper in press with exactly the same type cf observations and almost the same results. The only difference is that we used the brightness of Ca$^+$ mottles as indicator of the magnetic flux. However, our model calculations show that in order to fit the observed changes of the line profile and the C-shape with increasing magnetic activity, one has to diminish the number of ascending granules with constant intergranular area and fill the lack by "static" bright elements ("filigree"?). The comparison with your model calculations shows that there is some ambiguity in such model calculations.

KEIL — The number of free parameters in empirical models of the granulation permits us to match any line bisector shape. These computations can only serve as a guide to the range of variations within the convective overshoot region.

MATTIG — What is the spatial resolution of your data? You also find real C-shapes, but in my data presented this morning, I never found any C-shape but only straight lines.

KEIL — All of the spectra which I showed represent averages over large spatial areas and long temporal periods. All the profiles coming from areas within a set of magnetic contours were averaged, except for those showing strong darkening in the continuum (spots and pores) and also for those showing strong brightness enhancements in the core (line gaps due to facular points). Thus, the data have no spatial or temporal resolution at all. However, the "resolved" granular profiles which I have published before (with Frank Yackovitch[1] and in Keil 1984[2]) also show "straight" bisectors.

MÜLLER — Using line asymmetry observations performed at the Hida Observatory in Japan and high resolution photographs obtained from Pic du Midi near the same sunspot, we have found[3] that both the line asymmetry and the size of granules decrease when approaching the sunspot. Our observations also show that very few facular elements are present, the filling factor being less than 1%; they cannot contribute much to the observed line asymmetry. Thus, the decrease of the line asymmetry is correlated with the granule size decrease, similarly to the joint variation of line asymmetry and granule size over the solar cycle.

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